Front-End Electronics for the LEGEND Neutrinoless Double Beta Decay Experiment

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LEGEND

Large Enriched Germanium Experiment for Neutrinoless ββ Decay

The LEGEND Experiment

Mission

The collaboration aims to develop a phased, ^{76}Ge based double-beta decay experimental program with **discovery potential** at a half-life significantly longer than 10^{27} years, using existing resources as appropriate to expedite physics results [1].

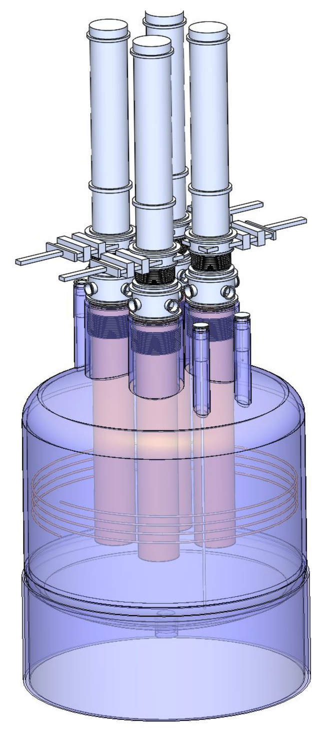
Staged approach

First stage (L200):

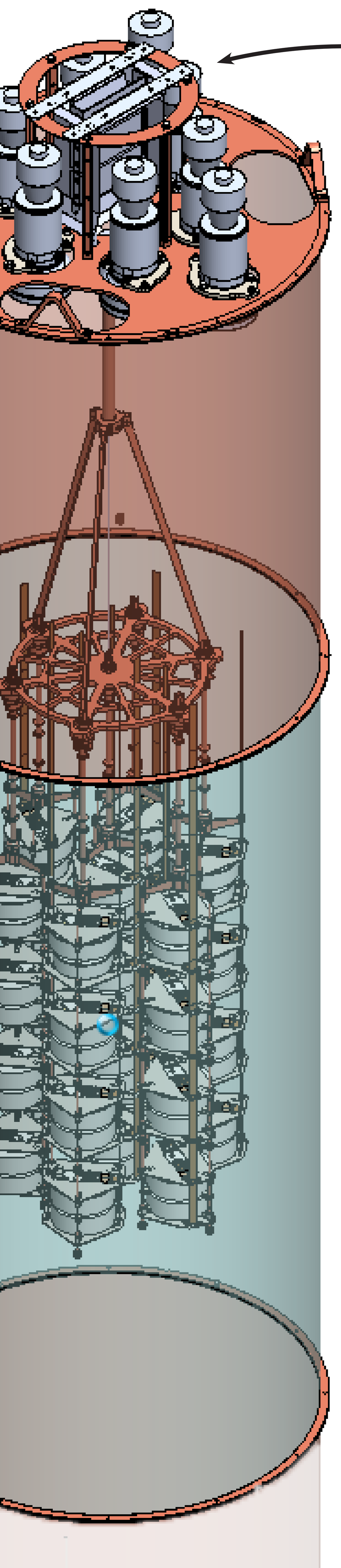
- Up to 200kg of Ge
- Modification of existing GERDA infrastructure at LNGS
- BG goal (x5 lower): 0.6 cts/(FWHM t yr)
- Start in 2021

Subsequent stages (L1000):

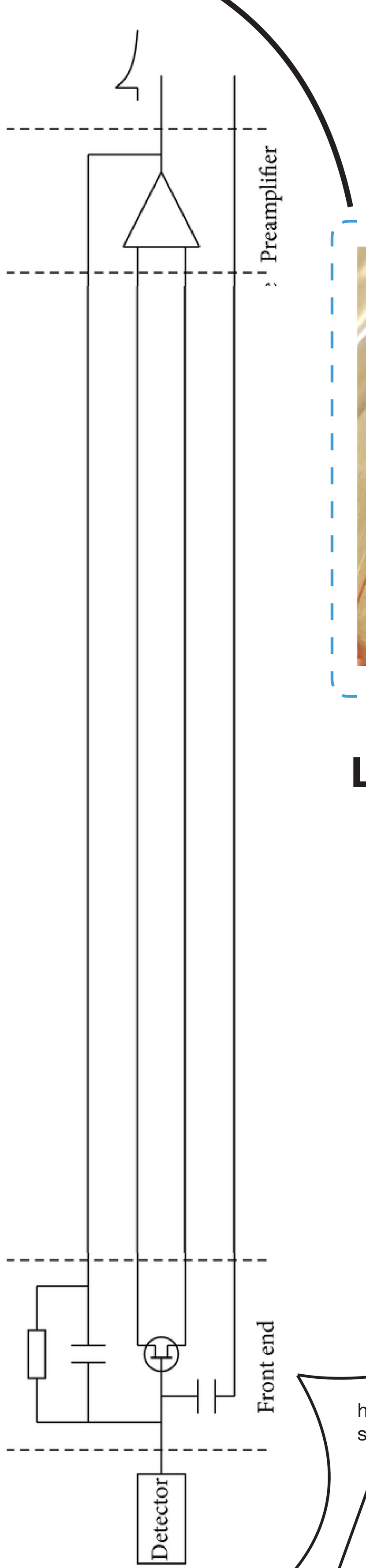
- 1000kg of Ge (staged)
- BG goal (x30 lower): 0.1 cts/(FWHM t yr)
- Location: TBD
- Required depth under investigation



Baseline Front-End Design for LEGEND 200



GERDA phase II string design (schematic) serving as a baseline for L200.



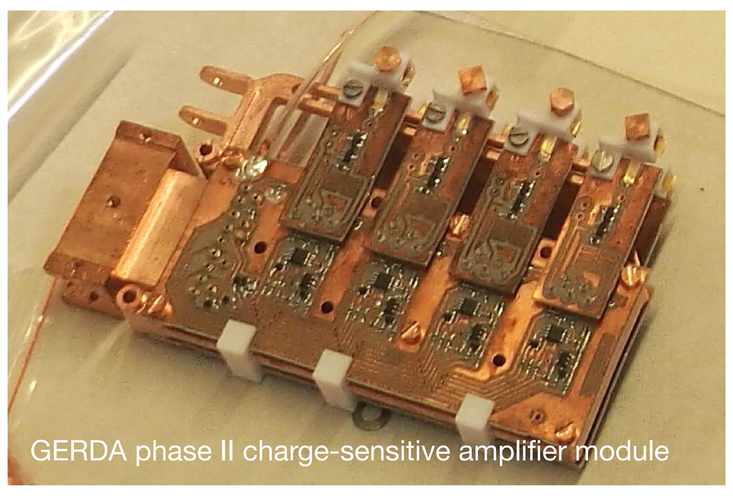
The baseline design for the LEGEND 200 combines elements from both the MAJORANA (MJ) and GERDA collaboration:

- **low-noise, low-background, front-end electronics** based on the MAJORANA LMFE (low mass front-end) [2].
- **charge sensitive amplifier (CSA)** based on the GERDA phase II design [3].

The overall goal for the L200 front end electronics is to:

- further improve radiopurity
- compatibility with a range of HPGe detectors (different capcitance): GERDA BEGe det., MJ PPC det., Inverted coax. det.)
- improve noise & possibly extend physics reach of LEGEND
- guarantee reliability at large-scale deployment

Charge sensitive amplifiers

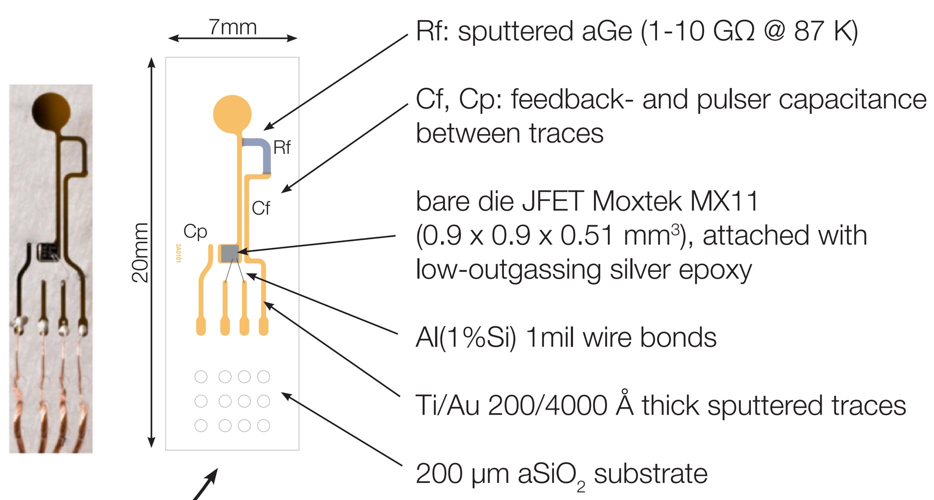


GERDA phase II charge-sensitive amplifier module

The GERDA collaboration has a long history of deploying charge sensitive amplifiers in liquid Argon. The L200 CSA will be based on the GERDA CC3 design. It be adapted to work with the LMFE and a differential output stage will be added to reduce nosie.

With the front end separated into two parts, the CSA is placed at a distance above the detector assembly and the stringend radiopurity requirements are slightly eased. The CSA is connected to the lock by ~ 12m long cables and to the LMFE by ~ 1m long cables. As the number of detectors will continuously grow, R&D efforts are ongoing to reduce the cable count (e.g., pulsing scheme) and improve background. For L1000, new readout schemes (e.g., highly integraded, ASIC-based, amplifiers) are currently investigated.

Low-mass front end electronics

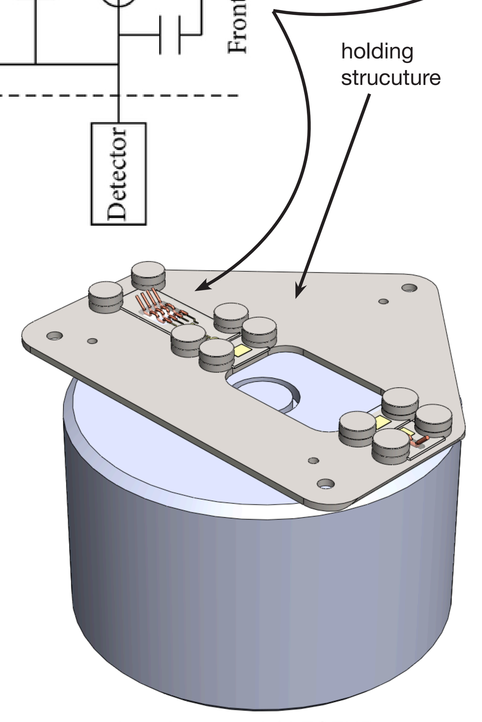


As the LMFE is placed in close proximity to the HPGe detectors, very stringent radiopurity constraints apply. This requires the LMFE to be small, very low in mass and restricts the components that can be placed there.

To achieve this, the LMFE is realised as a circuit board made from thin, sputtered Ti/Au traces on a SiO_2 substrate and stray capacitances between the traces. An in-die JFET is connected to the LMFE by silver epoxy and wire bonds. The contact between the detector and the LMFE will also be realised by wire bonds. The feedback resistor is a sputtered aGe thin film.

In order to further improve performance and radiopurity, modifications to this design are also being studied:

- alternative substrate materials (e.g., silicon, PEN).
- alternative in-die JFET (e.g., SF291).
- alternative resistors (e.g., Au nano-particles)
- contact solution between cables and LMFE



Artistic representation of a potential LEGEND detector unit, consiting of the LMFE, a silicon holding structure and a HPGe detector.

Amorphous Ge resistor

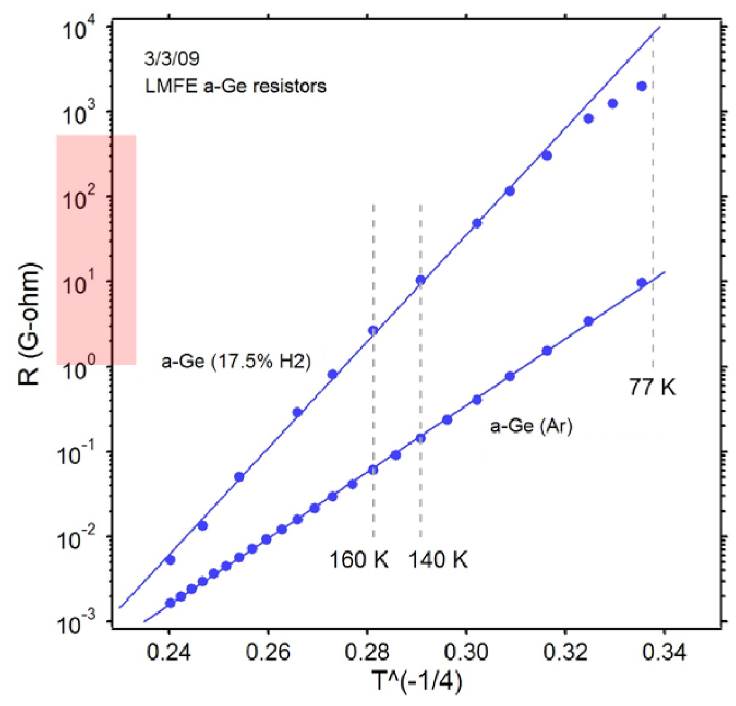
The Majorana LMFE is currently optimised for operation in vacuum cryostats where the heat dissipated by the JFET increases the temperature of the aGe resistor to ~ 90 K , resulting in Rf ~ 1-10 GΩ) [2] as the resistance scales with exp(1/T⁴).

When operated in liquid Argon (87 K), the aGe resistor shows a resistance of ~ 60-80 GΩ, resulting in long signal decay times. In liquid Nitrogen (77K), the resitance is even higher at ~ 160 - 200 GΩ.

R&D efforts are currently ongoing at LBL to optimise the aGe production parameters (e.g., sputter gas composition) and adapting the layout of the traces and resistor to achieve a resistance of R_f ~1-10 GΩ in LAr.

To investigate a time-dependent increase of the resistance value observed at TUM [4], further tests will be caried out (LBL & TUM):

- long-term storage and characterisation of aGe resistors in LAr.
- effects of passivation stability of resitance value

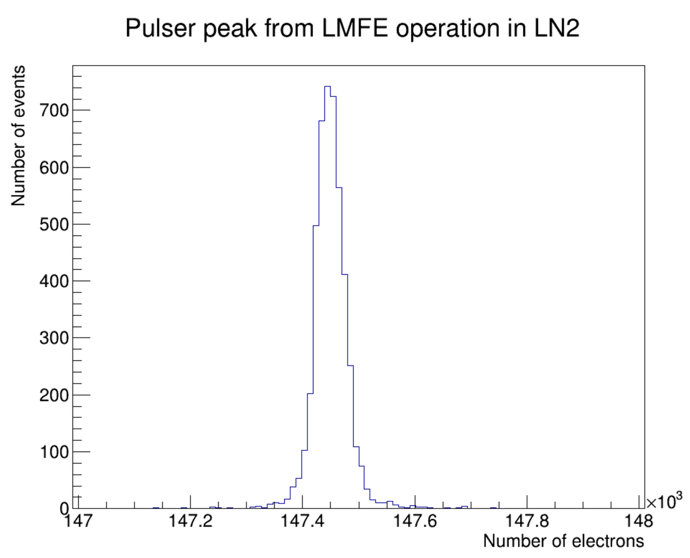


LMFE operation in LAr

Demonstrating LMFE operation and performance in LAr is crucial for the realisation of the L200 front-end electronics. Operation in LN2 has recently been demonstrated at LBL [5] and measurements with an electronic pulser show a noise of ~ 55 e⁻ (FWHM).

The next steps at LBL include:

- improving electronic noise of setup
- demonstrating operation in LAr
- tuning of RC on LMFE



LEGEND @ v2018

- LEGEND Overview - R. Massarczyk - Monday # 51
- Detector R&D strategy - Y. Keraidic - Monday # 41
- Preliminary Background Modelling - M. Green - Monday # 64
- ASIC based readout - F. Edzards - Monday # 96
- Inverted Coax HPGe detectors - T. Comellato - Monday # 109

NEUTRINO 2018 Heidelberg 4–9 June

References

[1] N. Abgrall et al. "The Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay (LEGEND)," arXiv:1709.01980.
[2] P. Barton et al., "Low-noise low-background front end electronics for low-background physics experiments using germanium detectors," 2011 IEEE Nuclear Science Symposium Conference Record, 2011.
[3] S. Riboldi et al., "Improvement of the "CC2" Charge Sensitive Preamplifier for the GERDA Phase II Experiment," IEEE NSS/MIC, 2012.
[4] T. Bode, "The neutrinoless double beta decay experiment GERDA Phase II: A novel ultra-low background contacting technique for germanium detectors and first background data", PhD Thesis, TUM, 2016.
[5] J. Myslik et al., "Performance of the MAJORANA Low-Mass Front-End in liquid cryogen," APS April Meeting 2018, Columbus, Ohio.

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